Meteorology and Air-Sea Fluxes from Ocean Reference Stations

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Introduction

Ocean reference stations are surface moorings deployed in key meteorological regimes around the world and equipped with sensors that sample meteorological and sea surface variables once per minute. At present, one station is operating under the stratus deck off of northern Chile (20° S, 85° W), and a second in the trade wind region of the northwest tropical Atlantic (15° N, 51° W). These two stations are in their fourth year of operation (moorings are refurbished annually). A third station is in preparation for deployment north of Hawaii.

The goal is to collect long time series of accurate surface meteorology, air-sea fluxes, and upper ocean variability and to use those data to

- Quantify air-sea exchanges of heat, freshwater, and momentum
- Describe the local oceanic response to atmospheric forcing (see companion poster by Colbo and Weller)
- Motivate improvements to numerical models and remote sensing products
- Provide anchor points for the development of new, basin scale flux fields (see companion poster by Yu, Weller and Jin)

The characteristics and performance of ocean reference stations are presented here, along with comparisons to other surface meteorology and flux products.

The ASIMET System

The Air-Sea Interaction Meteorology (ASIMET) system is a suite of meteorological and sea surface sensors that are deployed with different housings and packaging depending on the application. ASIMET modules (one or more sensors plus front-end electronics) may be self-powered and self-logging, connected to a central power supply and logger, or both. Together, these modules measure Air temperature (AT), relative humidity (RH), sea surface temperature and conductivity (SST, SSC), wind speed and direction (WSPD, WDIR), barometric pressure (BP), shortwave radiation (SWR), longwave radiation (LWR), and precipitation (PRC). These variables are used to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas.

Figure 1: The Northwest Tropical Atlantic Station (NTAS) buoy at sea.

On buoys, modules are packaged in titanium cylinders that include provisions for batteries and internal logging. Buoy modules are typically deployed in pairs, with 6 meteorological module pairs mounted on the buoy tower (Fig 1) and a pair of temperature-conductivity sensors attached to the bridle leg. A central logger records one minute data from all the modules on a common time base, and also creates hourly averaged data that are transmitted to shore via Argos satellite telemetry.

The same ASIMET sensors and electronics, with some differences in packaging, are also deployed on Volunteer Observing Ships (see poster by Hosom et al.).

Sensor Calibration

All ASIMET sensors are calibrated relative to accurate standards and lab-tested at WHOI before and after deployment (Figs. 2-4). During the preparation phase, three complete systems are run outdoors for 1–3 months, and the resulting data are evaluated for quality and consistency. Two systems, comprised of the best performing modules, are deployed on the buoy. Immediately after deployment, and again just prior to recovery, the telemetered data from the buoy are monitored and compared with shipboard sensors. The buoy sensors are retrieved and post-calibrated after one year in the field. For VOS systems, the logger and sensors are retrieved every 6 months for repair and calibration.

Figure 2. The Thunder Scientific humidity chamber at the WHOI calibration facility. Relative humidity sensors are calibrated at 5 %RH intervals from 20-95 %RH.]

Figure 3 (left). Components of the pressure sensor calibration system. Barometric pressure sensors are calibrated at 10 hPa intervals from 980-1040 hPa using a DHI PPC2+ pressure standard.

Figure 4 (right). Radiometer test facility on the roof of Clark Laboratory at WHOI. Shortwave and longwave sensors are calibrated at Eppley and at WHOI, respectively, and then compared with Eppley PSP and Kipp & Zonen CG-4 secondary standards calibrated by the National Renewable Energy Laboratory (NREL) using the rooftop test facility

ASIMET Sensor Performance

Table 1. ASIMET Sensor Performance

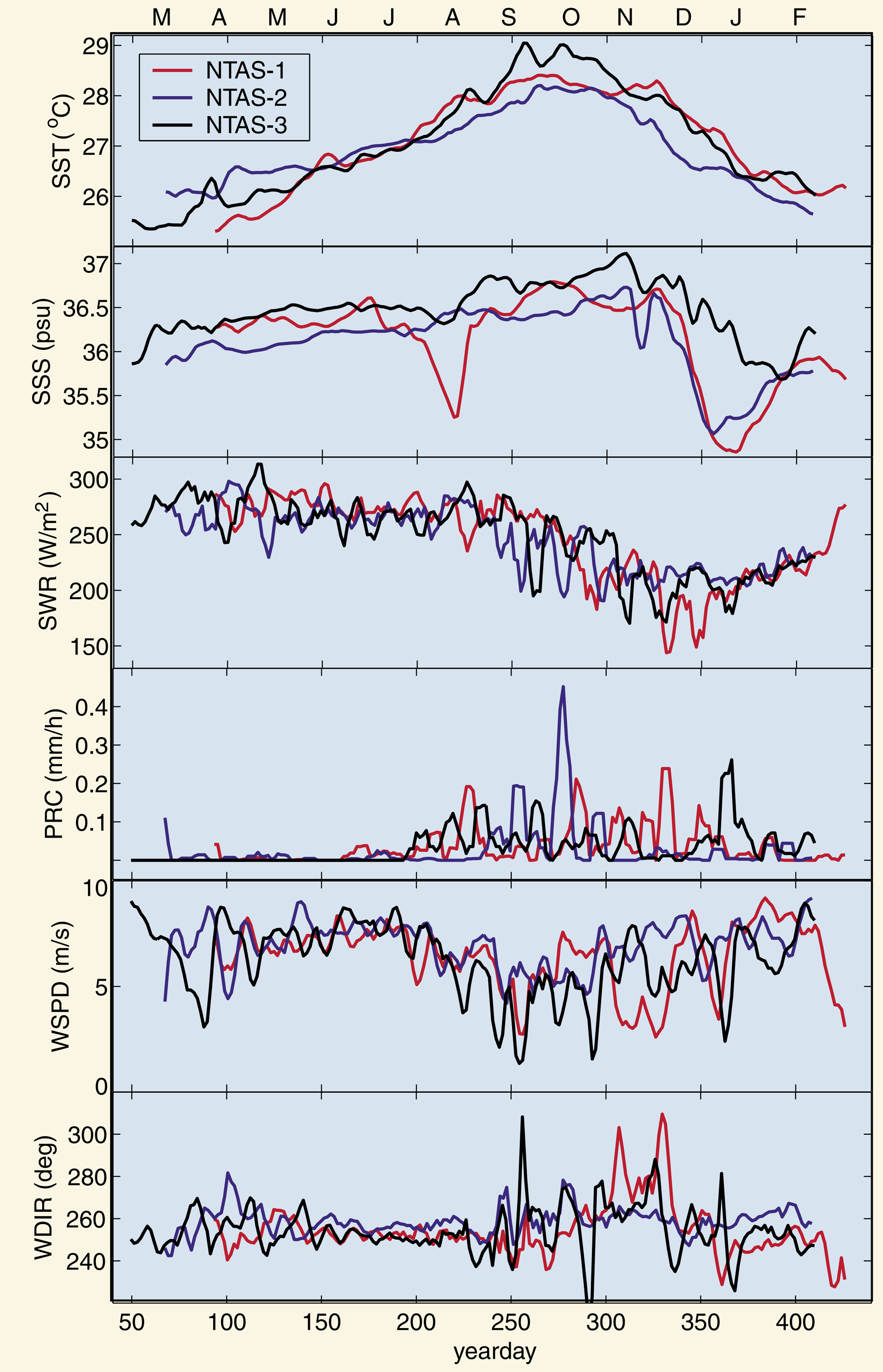
Label	Variable	Sensor	Precision	LabCal [1] Accuracy	Field [2] Accuracy	NTAS-2 Diff [3] Mean	NTAS-2 Diff [3] Std Dev
AT	air temperature	Rotronic	0.01 °C	0.05 °C	0.1 °C	0.06 °C	0.07 °C
RH	relative humidity	Rotronic	0.01 %RH	0.5 %RH	3 %RH	0.3 %RH	0.6 %RH
BP	barometric pressure	AIR Inc.	0.01 mb	0.1 mb	0.5 mb	0.6 mb	0.1 mb
SST	sea temperature	SeaBird	0.1 m°C	5 m°C	0.1°C	0.5 m°C	5.5 m°C
SSS	sea conductivity	SeaBird	0.01 mS/m	5 mS/m	10 mS/m	0.8 mS/m	1.4 mS/m
PRC	precipitation	RM Young	0.1 mm	0.5 mm	1 mm/h	0.2 mm/h	15 mm/h [4]
LWR	longwave radiation	Eppley PIR	0.1 W/m^2	5 W/m^2	10 W/m^2	15.5 W/m^2	3.1 W/m^2
SWR	shortwave radiation	Eppley PSP	0.1 W/m^2	2%	3%	0.2% (1.7 W/m^2)	7.8% (24.5 W/m^2)
WSPD	wind speed	RM Young	0.1 m/s	2%	5%	0.04% (0.2 cm/s)	3.7% (0.2 m/s)
WDIR	wind direction	RM Young	0.1 deg	2 °	3 °	2.4 °	2.2 °

[1] Typical accuracy for pre- and post- deployment laboratory calibrations
[2] Expected accuracy for open-ocean deployment on a surface buoy
[3] Statistics from NTAS-2 sensor pairs using 1 min logger data
[4] Statistics computed only when one or both sensors indicated rain

Since the sensors are referenced to known standards in pre- and post-calibrations, we would expect mean differences between like variables during buoy deployments to reflect the laboratory calibration accuracy. As an example, we show data from the Northwest Tropical Atlantic Station (NTAS; 15°N, 51°W). Table 1 shows that the ASIMET sensors generally performed very well. The exceptions were BP and LWR. The BP difference indicated a nonlinear drift, which was not accounted for in the post-calibration. The LWR difference was nearly constant, but accurate calibration data are not yet available to determine the appropriate correction. Note that field accuracies, which are affected by factors such as platform motion, flow distortion, and self-heating, may be notably larger than either lab calibration accuracies or sensor pair differences.

Time Series Data

The annual cycle of surface meteorology at the NTAS site is depicted by selected meteorological variables averaged over 1 week on a 13 month time base (Fig. 5). Spring (MAM) is characterized by SST increasing from its annual minimum and very low levels of precipitation. Summer (JJA) is characterized by steady west winds (towards 255°) at 6-8 m/s and continuing increases in SST. Episodic precipitation begins in late summer. Fall (SON) is characterized by reduced solar radiation, SST decreasing from its annual maximum, persistent precipitation, and variable winds. By mid winter (DJF), solar radiation begins to increase, precipitation decreases, and winds become steadier. A surface salinity minimum is observed in winter, and is particularly dramatic in the first two years.



[Figure 5. Time series of sea surface temperature (SST), sea surface salinity (SSS), downwelling shortwave radiation (SWR), precipitation rate (PRC), wind speed (WSPD) and wind direction (WDIR) for NTAS deployments in 2001 (NTAS-1, red), 2002 (NTAS-2, blue) and 2003 (NTAS-3, black).]

For More Information

The Upper Ocean Processes Group: http://uop.whoi.edu
Archived surface mooring data: http://uop.whoi.edu/uopdata
The ASIMET system: http://frodo.whoi.edu
VOS Climate Project: http://uop.whoi.edu/vos

Comparison with NWP Models

Table 2. NWP Models - ASIMET

Label	Variable	Units	ECMWF Mean	ECMWF StdDev	NCEP Mean	NCEP StdDev
AT	air temperature	°C	0.1	0.6	-0.2	0.6
SH	specific humidity	g/kg	-0.4	0.6	0.7	0.9
BP	barometric press	mb	0.2	0.6	-5.2	2.0
SST	sea temperature	°C	-0.2	0.4	-0.3	0.3
PRC	precipitation	mm/hr	0.1	0.3	0.1	0.3
LWR	longwave rad	W/m^2	3	11	-1	16
SWR	shortwave rad	W/m^2	-24	77	1	85
WSPD	wind speed	m/s	-0.7	1.2	0.0	1.4
WDIR	wind direction	deg	6	14	-1	14
Qs	sensible heat	W/m^2	0	6	-2	9
Ql	latent heat	W/m^2	-15	31	-12	46
SWn	net shortwave	W/m^2	-21	72	-20	81
LWn	net longwave	W/m^2	2	11	-3	16
Qnet	net heat flux	W/m^2	-33	77	-37	90

As an example of ASIMET meteorology and fluxes vs. Numerical Weather Prediction (NWP) models, we show results from the NTAS-1 deployment compared to model products from ECMWF and NCEP. The ASIMET data were from the best performing sensors on the buoy. The ECMWF data were the output of the diagnostics module (DDH) for the grid point of the operational model nearest the buoy. The NCEP data were extracted from the nearest grid point in the first NCEP/NCAR Reanalysis data set. The ASIMET (1 min) and ECMWF (1 h) data were averaged over six hours to match the NCEP time base. The results are shown in Table 2.

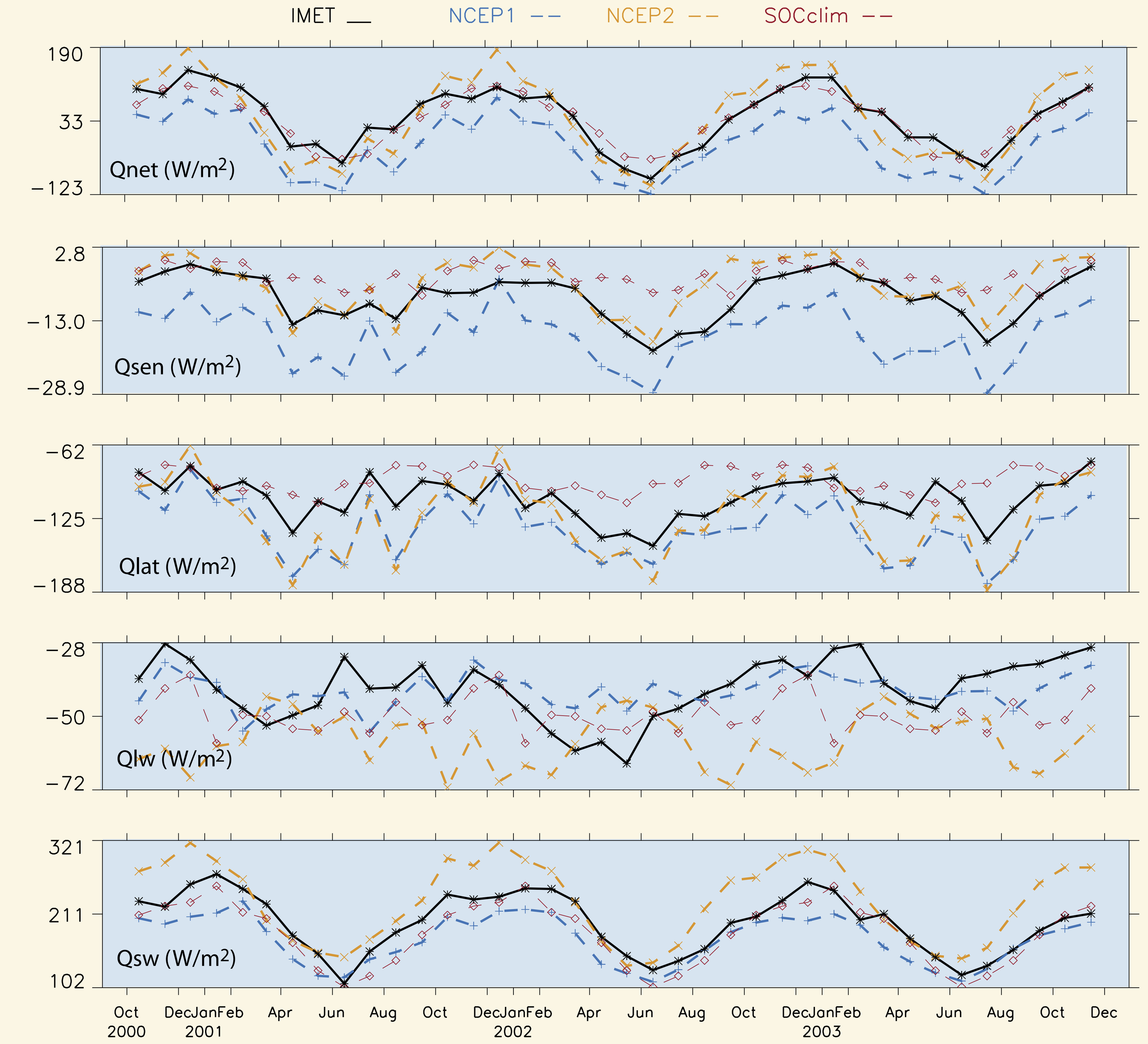
For many of the meteorological variables the mean differences are within the expected accuracy of the buoy sensors. The most notable discrepancies are NCEP BP and ECMWF SWR. In addition, SWR, WSPD, and WDIR have difference standard deviations much greater than the sensor accuracy, indicating significant discrepancies in the model fields on short time scales.

The difference statistics for heat flux components indicate that the models to relatively well in estimating Qs and LWnet, but have significant errors in Ql and SWnet. The mean errors in Qnet are 2-3 times larger than the expected error of 10-15 W/m² from the buoy. The large difference standard deviations for Qnet indicate that both models have shortfalls in capturing variability on short time scales.

Heat Flux Comparisons

A three year record of monthly average heat flux from the STRATUS mooring in the southeast tropical Pacific (20°S, 85°W) is used to illustrate comparison of in-situ and modeled fluxes (Fig. 6). NWP results are represented by the NCEP Version 1 and 2 reanalysis-forecast models. Flux climatology from the Southampton Oceanography Center (SOC), which is based on VOS reports from 1980-1993, is also included. The in-situ fluxes were computed using the TOGA COARE bulk flux algorithm (2.6b), whereas the NWP models and the SOC climatology use their own flux algorithms.

A distinct seasonal cycle is evident in the net heat flux, which is echoed in the sensible and shortwave components. Seasonal variability is less dramatic in latent and longwave fluxes, but short term variability is more evident. In general, short-term discrepancies of tens of W/m² and persistent biases of up to 50 W/m² relative to the in-situ data are indicative of the shortcomings of NWP fluxes. The NCEP-2 and SOC fluxes are a reasonably good match to the in-situ net heat flux, and NCEP-2 latent heat flux shows a distinct improvement over NCEP-1. However, the improved NCEP-2 net heat flux appears to have come at the expense of an increased longwave radiation bias and uncomfortably large seasonal errors in shortwave radiation.



[Figure 6. Time series of monthly averaged surface heat flux components. In-situ fluxes computed from ASIMET surface meteorology on the STRATUS mooring (20° S, 85° W) are compared with fluxes from the NCEP version 1 and 2 reanalysis. The SOC flux climatology is also shown.]